Chapter 3
Basic Considerations

3-1. Foundation Investigations

The design of a relief well system should be preceded by thorough field and geologic studies conducted in accordance with EM 1110-1-1804. Sufficient borings should be made to define seepage entrance and exit conditions, the depth, thickness, and physical characteristics of the pervious strata, as well as the thickness and physical characteristics of the top stratum in upstream or riverside areas and downstream or landside areas. See Appendix B for further details. Particular attention should be given to the presence of buried channels and pervious abutments which could impact on underseepage estimates. An example of a generalized soil profile for relief well design along a levee reach is shown in Figure 3-1. The influence of surficial deposits on levee underseepage and on relief well design may be noted in Figure 3-2. High exit gradients and concentrations of seepage which may occur adjacent to clay-filled swales or channels will often govern the locations of individual relief wells. Where soil conditions vary along the proposed line of wells, the profile can be divided into a series of design reaches as shown in Figure 3-3. Additional borings, as subsequently described, should be made after completion of final design to ensure that a boring is located within 5 ft of each final well location. In general, samples should be taken at intervals not greater than 3 ft or at changes of soil strata, whichever occur first.

3-2. Foundation Permeability

Preliminary estimates of foundation permeability can be made from laboratory tests or correlations with grain size as described in EM 1110-2-1901. Because sampling operations do not necessarily indicate the relative perviousness of foundations containing large amounts of gravelly materials, field pumping tests are recommended to verify the foundation permeability on all projects where the use of pressure relief wells is being considered. The test well should fully penetrate the pervious aquifer, and a well flow meter should be used to determine the variations in horizontal permeability with depth. An example of data derived from a field pumping test conducted in this manner is shown in Figure 3-4. Field pumping test procedures for steady state and transient flow conditions are given in Appendix III to TM 5-818-5. Additional information, including procedures for field permeability tests in fractured rock, is given in EM 1110-2-1901. The vertical permeability of individual strata can be estimated from laboratory tests on undisturbed samples or determined from field pumping tests (Mansur and Dietrich 1965).

3-3. Anisotropic Conditions

Analytical methods for computing seepage through a permeable deposit are based on the assumption that the permeability of the deposit is isotropic. However, natural soil deposits are stratified to some degree, and the average permeability parallel to the planes of stratification is greater than the permeability perpendicular to these planes. Thus, the soil deposit actually possesses anisotropic permeability. To make a mathematical analysis of the seepage through an anisotropic deposit, the dimensions of the deposit must be transformed so that the permeability is isotropic. Each permeable stratum of the deposit must be separately transformed into isotropic conditions. In general, the simplest procedure is to transform the vertical dimensions with the horizontal dimensions unchanged.

3-4. Chemical Composition of Ground Waters

Some ground waters are highly corrosive with respect to elements of a pressure relief well or may contain dissolved minerals or carbonates which could in time cause clogging and reduced efficiency of the well. The chemical composition of the ground water, including river or reservoir supply waters, should be determined as part of the design investigation. Sampling, sample preservation, and chemical analyses of ground water is covered in handbooks (Moser and Huibregtse 1976, Environmental Protection Agency 1976). Indications of corrosive and incrusting waters are given in Table 3-1. The chemical composition of ground water is a major factor in the chemical and biological contamination of well screens and filter packs as described in Chapter 11.

3-5. Seepage Analysis

The determination of whether relief wells are needed is based on a seepage analysis which also provides the conditions for design of the relief well system. The seepage analysis defines the entrance and exit conditions and provides an estimate of substratum pressures which may exist under project flood conditions. On completed structures where piezometric data are available, seepage analyses are required to permit extrapolation of the data to the project flood conditions. The mathematical analysis of underseepage and substratum pressures is contained in Appendix B.

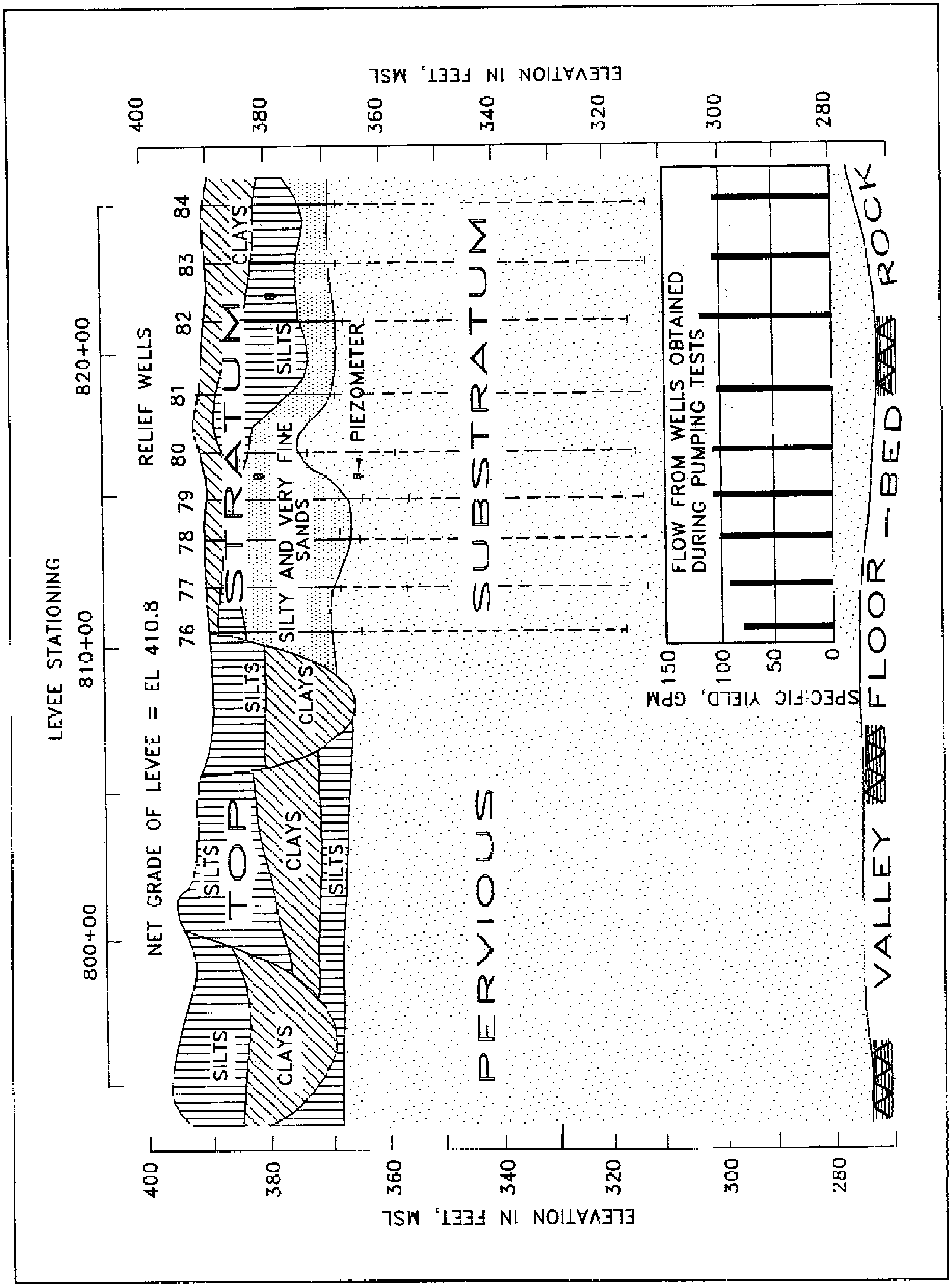


Figure 3-1. Soil profile, relief well, and piezometer installation data

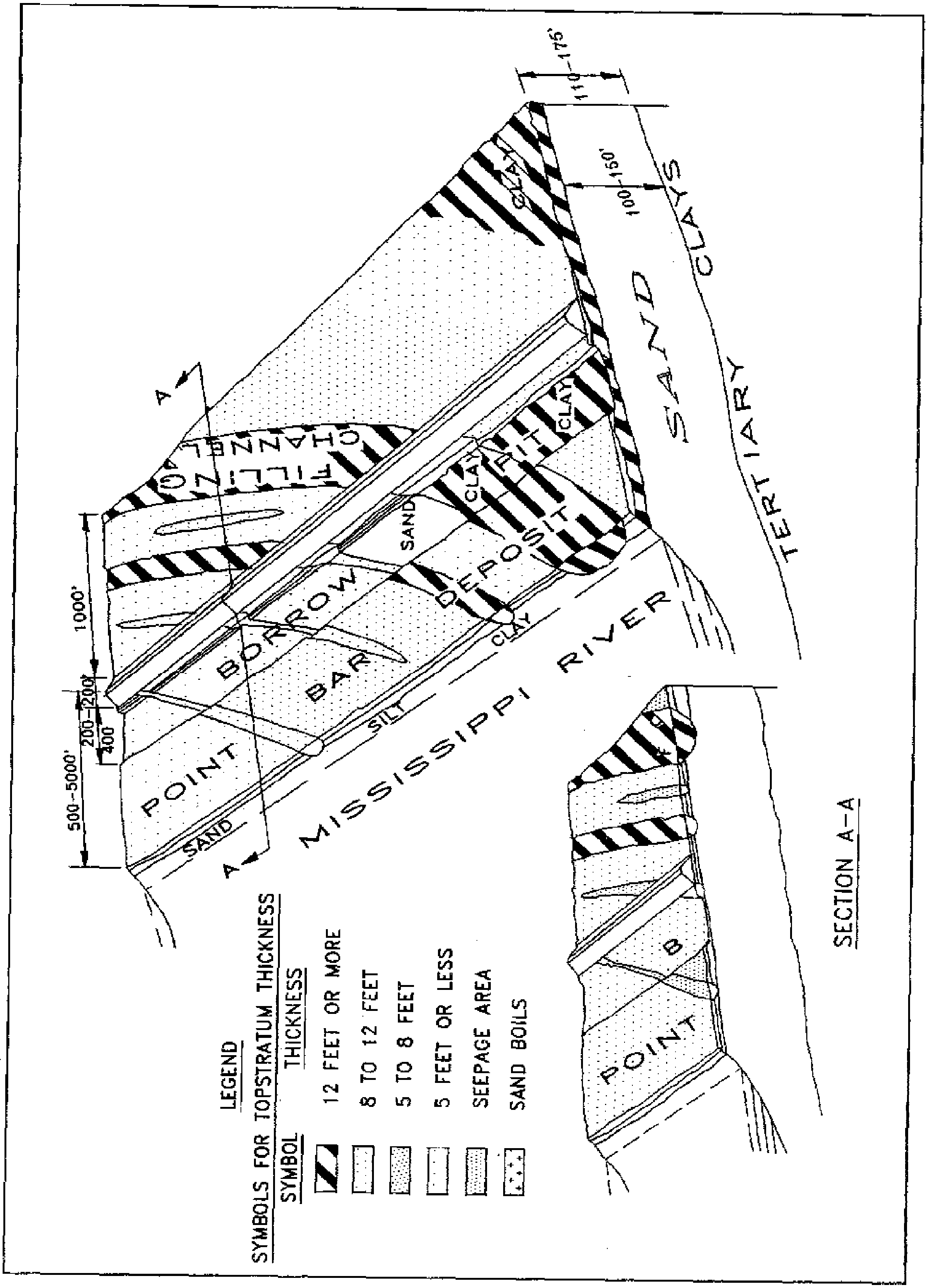


Figure 3-2. Seepage through point bar deposits

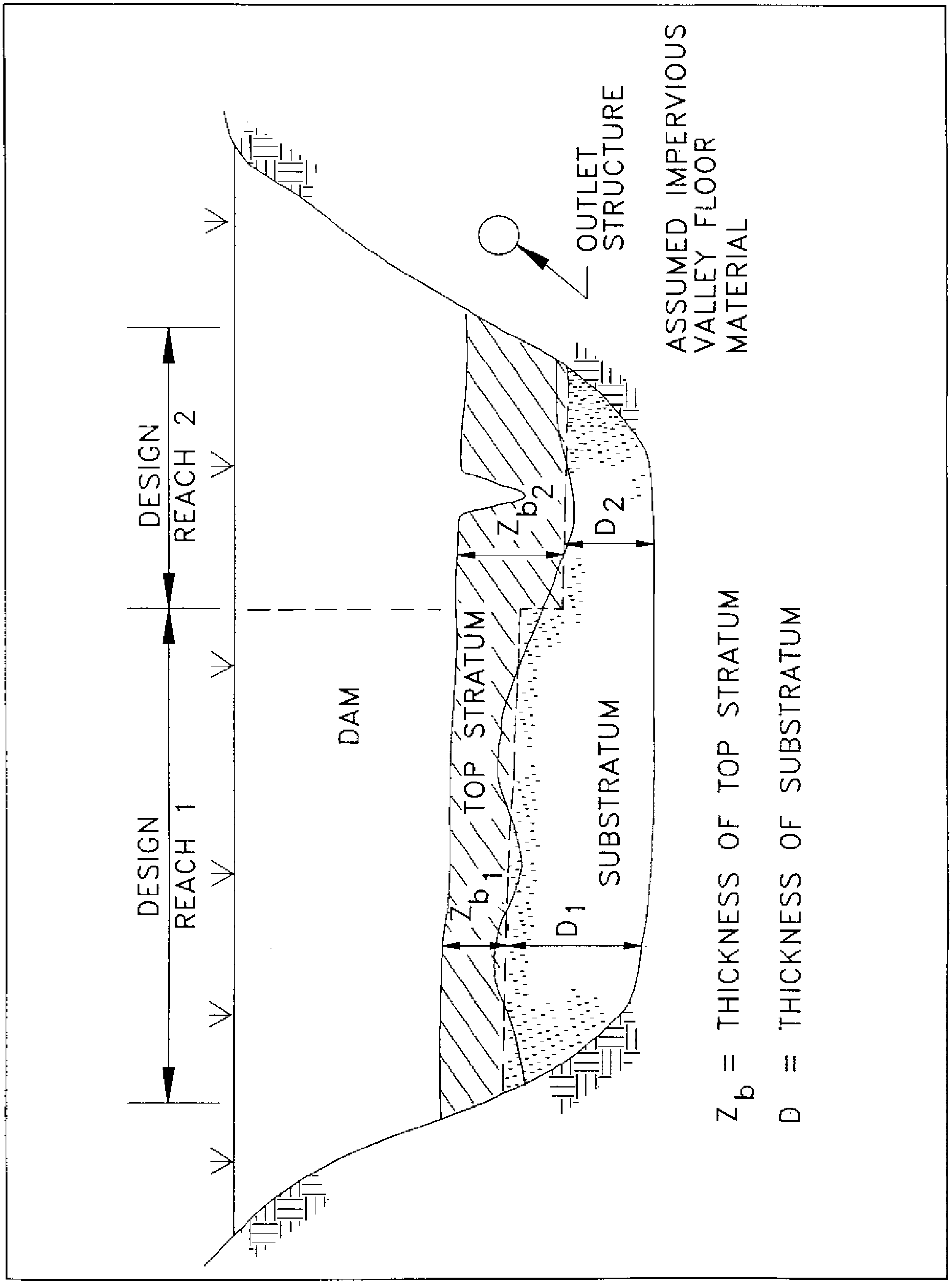
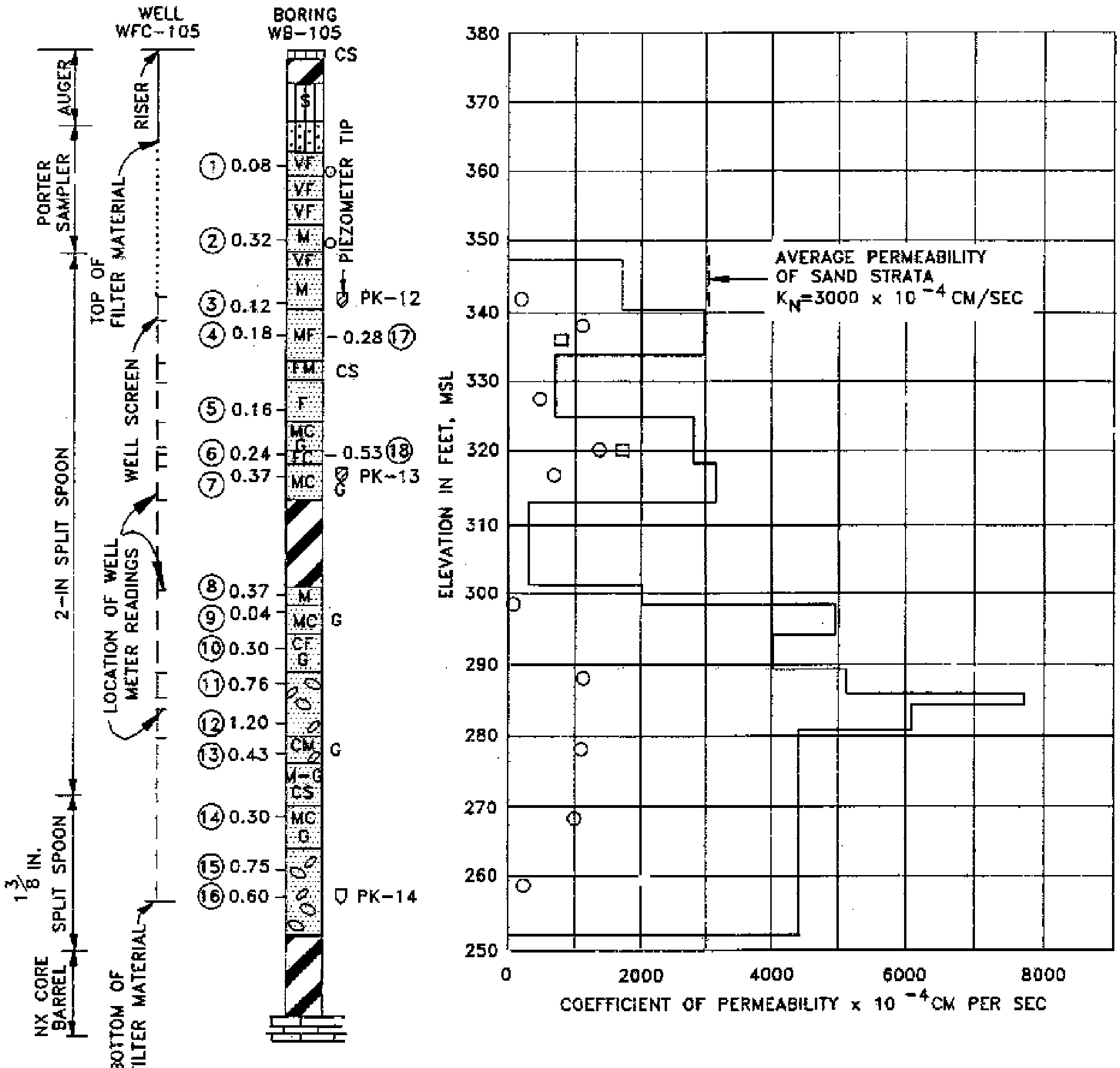


Figure 3-3. Profile of typical design reaches for relief well analysis



NOTE:

1. WELL FC-105 LOCATED AT LEVEE STA 301+25. FT. CHARTRES LEVEE DISTRICT. APPROX. 45 MILES SOUTH OF ST. LOUIS.
2. PERMEABILITIES SHOWN BY BAR GRAPH WERE COMPUTED FROM WELL METER AND PIEZOMETER READINGS.
3. PERMEABILITIES SHOWN BY ○ AND □ WERE OBTAINED FROM LABORATORY TESTS ON BORING AND WELL DRILLING SAMPLES, RESPECTIVELY, AND WERE ADJUSTED TO THE ESTIMATED NATURAL VOID RATIO BY THE FORMULA $K_n = K_L \times (e_n / e_L)^2$ AND CORRECTED TO $T = 20°C$.
4. FIGURES TO THE LEFT OF BORINGS ARE D_{10} IN MM, OBTAINED FROM BORING SAMPLES; THOSE TO RIGHT OF BORING FROM WELL DRILLING SAMPLES.
5. CIRCLED NUMBERS REFER TO GRAIN SIZE CURVES.

Figure 3-4. Coefficient of permeability and effective gain size of individual sand strata - Well FC-105

Table 3-1
Indicators of Corrosive and Incrusting Waters[a]

Indicators of Corrosive Water	Indicators of Incrusting Water
1. A pH less than 7	1. A pH greater than 7
2. Dissolved oxygen in excess of 2 ppm[b]	2. Total iron (Fe) in excess of 2 ppm
3. Hydrogen sulfide (H_2S) in excess of 1 ppm detected by a rotten egg odor	3. Total manganese (MN) in excess of a 1 ppm in conjunction with a high pH and the presence of oxygen
4. Total dissolved solids in excess of 1,000 ppm indicates an ability to conduct electric current great enough to cause serious electrolytic corrosion	4. Total carbonate hardness in excess of 300 ppm
5. Carbon dioxide (CO_2) in excess of 50 ppm	
6. Chlorides (CL) in excess of 500 ppm	

Notes:
a. From TM 5-818-5.
b. ppm = parts per million.

3-6. Allowable Heads

Whenever a structure underlain by pervious deposits is subjected to a differential hydrostatic head, seepage enters the pervious strata, creating an artesian pressure beneath the structure and downstream areas which could result in piping or failure by heave of the downstream top stratum. Pressure relief wells are designed to prevent piping and provide an adequate factor of safety, *FS*, with respect to uplift or heave. For this purpose, reduce the net head beneath the top stratum in downstream areas to an allowable value, h_a. The equation for *FS* is

$$FS = \frac{i_o}{i_c} = \frac{\gamma'/\gamma_w}{h_a/Z_t} = \frac{\gamma' Z_t}{\gamma_w h_a} \tag{3-1}$$

where

i_c = critical upward hydraulic gradient, the ratio of the submerged weight of soil, γ', to the unit weight of water, γ_w

Z_t = transformed thickness of downstream top stratum (see Appendix B)

The factor of safety with respect to uplift or heave normally should be at least 1.5. In addition to providing a minimum factor of safety with respect to uplift of heave (Condition a), relief wells may also be designed to ensure that piezometric heads in downstream areas are below ground surface, thereby preventing upward seepage from emerging beneath the downstream top stratum (Condition b). The latter condition usually applies to dams where visible seepage in downstream areas is undesirable and can be prevented by installing the wells with outlets in ditches or collector pipes along the embankment toe. The two conditions are illustrated in Figure 3-5.

a. Condition a. The allowable net head (h_a) under the top stratum of the downstream toe for this condition is given by

$$h_a = \frac{i_c}{FS} Z_t \tag{3-2}$$

b. Condition b. The maximum downstream piezometric surface is defined by Δh_d which is the difference between this surface and the elevation of the well outlets corrected for well losses as subsequently described. For wells discharging into a collector ditch,

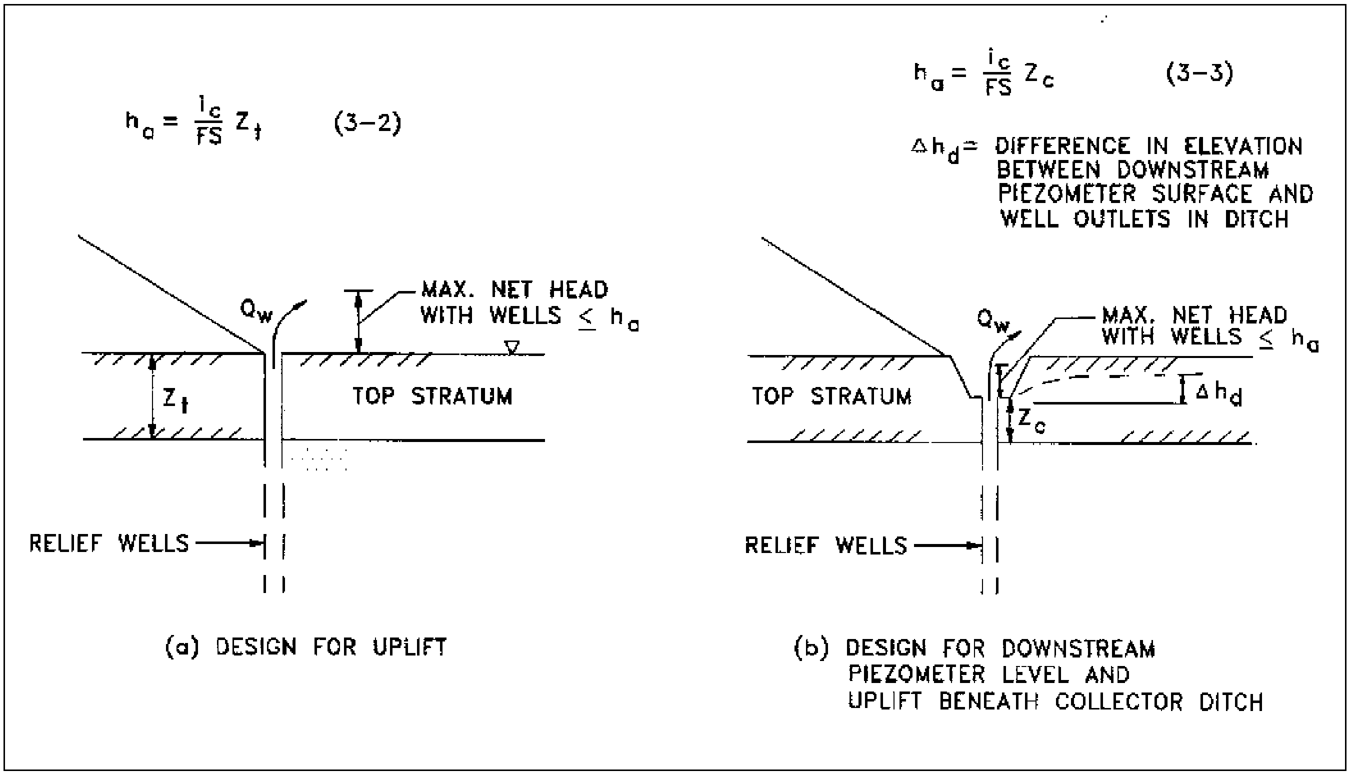


Figure 3-5. Determination of allowable heads in downstream toe area

the factor of safety with respect to uplift below the bottom of the collector ditch should be at lease 1.5. The allowable net head under the top stratum below the bottom of the collector ditch for this condition is given by the equation

$$h_a = \frac{i_c}{FS} Z_c \qquad (3\text{-}3)$$

where Z_c is the transformed thickness of the downstream top stratum below the bottom of the collector ditch.